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Design of deaerator storage vessel for hydrotest condition in fully assembled position

Deaerators are mechanical equipment used to remove dissolved gases from boiler feedwater to protect the steam system from the effects of corrosive gases. This is accomplished by reducing the concentration of dissolved oxygen (O_2) and carbon dioxide (CO_2) with temperature increase in a heating vessel or deaeration vessel. Treated or deaerated water is then stored in a larger storage vessel located beneath the deaeration vessel.

A typical deaerator assembly consists of a deaeration vessel mounted directly on a storage vessel. For such assemblies, the mechanical design of lower equipment must account for the operating weight of top-mounted equipment, per standard industry practice. Individual equipment is hydrotested separately. However, the situation becomes challenging if such equipment must be designed for hydrotest condition in an assembled position. In this case, the storage vessel must be designed for the hydrotest weight of the deaeration vessel. This will have a major design impact for the storage vessel, which is usually very large in size, as it will considerably increase the shell thickness of the storage vessel.

This article describes how the storage vessel can be designed for the hydrotest weight of the deaeration vessel but within the limit of the thickness required by design conditions. An example illustrating the details of design, which will save project costs, is included.

Deaerator configurations.

A complete deaerator installation usually includes a deaeration device and provisions for holding a quantity of deaerated water in reserve. The deaeration device and storage vessel are provided in a two-vessel design.

In the two-vessel arrangement, the deaeration devices are installed in a smaller vessel that is separate from the storage vessel and mounted on the top. The storage vessel is always a horizontal vessel. The top deaeration vessel can be vertical or horizontal (FIG. 1). In such an arrangement, the top vessel deaerator is supported directly on the storage vessel.

Storage vessel design—traditional method.

The mechanical design of the deaerator vessel and storage vessel are commonly covered by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, Division I.[1]

Traditional industry practice is to design the deaeration and storage vessels as individual equipment and hydrotest them separately. The top deaeration vessel is directly mounted on the storage vessel, so the design of the storage vessel must consider the operating weight of the deaeration vessel for calculating the shell thickness of the storage vessel.

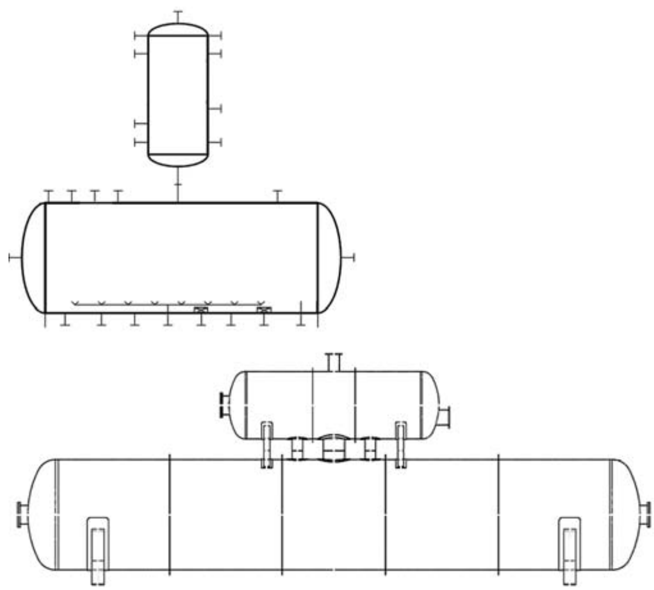

FIG. 1. Vertical deaeration vessel (top) and horizontal deaeration vessel (bottom).

Storage vessel design for hydrotest weight.

Sometimes, client specifications include stringent requirements for hydrotesting a fully assembled deaerator instead of hydrotesting individual deaerator vessels and storage tanks. This is required for the following reasons:

1. Leak testing of interconnecting flanges between the deaerator vessel and storage tanks.
2. To mitigate any upset conditions that could result in overfill of the deaerator vessel, which does not store fluid in the normal operating condition.
3. Any future repair work at the site that would require site hydrotesting of the deaerator. Since the deaerator is installed on an elevated structure, it is unlikely to be lowered to grade for hydrotesting; therefore, it must be hydrotested in the installed, assembled condition.

In a hydrotest, the equipment is fully filled with water, and test pressure is applied at the highest point. The hydrotest

weight is the weight of the empty vessel and the weight of the vessel full of water. The latter can be easily calculated by multiplying the inside volume of the equipment by the water density.

A deaerator normally operates with the storage vessel only partially filled with liquid. During the hydrotest, the entire assembly (i.e., the deaerator vessel and storage vessel) is fully filled with water, which adds substantial weight to the assembly and becomes a mandatory design condition to be evaluated. The bottom storage vessel must be designed for the loads of the top-mounted deaeration vessel in the hydrotest condition. The shell thickness of the storage vessel is based on the hydrotest weight of the deaeration vessel instead of its operating weight. This would result in a drastic increase of the shell thickness of the bottom storage vessel, along with a very high cost. An example is illustrated in the following section, along with a resolution explaining how a storage vessel can be designed for the hydrotest weight of a deaeration vessel but within the thickness limit required by the design conditions.

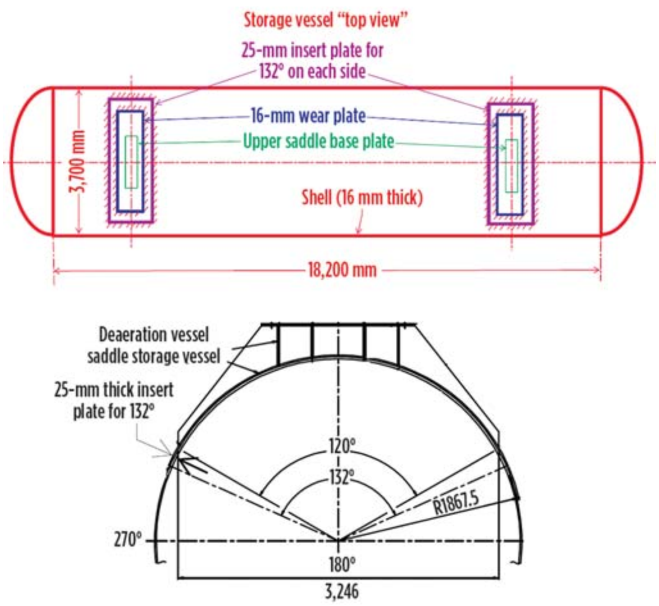

FIG. 2. Storage vessel sketches with technical details.

Example for horizontal deaerator. Consider a typical horizontal deaerator with an inner diameter (ID) of 2.5 m × t/t 10.2 m, and a storage vessel with an ID of 3.7 m × t/t 18.2 m. The entire deaerator assembly must be designed per ASME Section VIII, Division 1. The design pressure and temperature is 6 barg and full vacuum at 235°C. The material of both vessels is carbon steel. The deaeration vessel is saddle-supported on the storage vessel.

Three case designs are explained to show the thickness requirement:

1. **Design Case 1—Traditional design:** The deaeration and storage vessels are designed as individual equipment, per traditional industry practice, and will be hydrotested separately. The storage vessel must be designed considering the operating weight (26.5 t) of the

deaeration vessel. This would require a shell thickness for the storage vessel of 16 mm. The empty weight of the storage vessel in this design case is 35,500 kg.

2. **Design Case 2—Hydrotest design:** The deaeration and storage vessel are designed for the hydrotest condition in the operating position rather than as individual equipment, per traditional industry practice. They will be hydrotested in the assembled position. The storage vessel must be designed considering the hydrotest weight (74 t) of the deaeration vessel. This would require a shell thickness for the storage vessel of 24 mm. The empty weight of the storage vessel in this design case is 52,500 kg. The empty weight of the storage vessel will be increased by 48% over the traditional design; therefore, the material cost will be greater.
3. **Design Case 3—Hydrotest design with required traditional thickness:** The deaeration and storage vessels are designed for the hydrotest condition in the operating position. Both will be hydrotested in the assembled position. The storage vessel must be designed considering the hydrotest weight (74 t) of the deaeration vessel. The shell thickness of the entire storage vessel will be maintained at 16 mm, except at the saddle supports of the deaeration vessel. A thicker insertion plate will be added on the bottom of the storage vessel shell where the top deaeration vessel is supported.

Insertion plates are commonly used to strengthen nozzles and as supports for piping, ladders and platforms with high local loads. However, the use of an insertion plate for supporting equipment is rarely seen in industry.

An in-house calculation was performed for the local load analysis, using Welding Research Council (WRC) Bulletin 107/537,[2] at the location of the deaerator vessel supports on the storage vessel shell. The calculation results indicated that a 25-mm insertion plate needed to be added on the bottom storage vessel at the location of the supports of the top-mounted deaeration vessel. This will avoid an increase in the shell thickness of the bottom storage vessel from 16 mm to 24 mm. Sketches with technical details are shown in **FIG. 2.**

The design shown in **FIG. 2** would result in a cost savings of approximately $45,000 due to savings in the material weight of the storage vessel of around 17,000 kg. A reduction in the weight of the storage vessel can also help optimize costs related to shipping, erection and the structure on which the storage vessel will be installed.

Recommendations. The traditional design method considers the deaerator vessel and storage vessel as individual equipment and advises separate hydrotests to avoid an increase in the shell thickness of the storage vessel. This increase in shell thickness would be due to the hydrotest weight of the storage vessel mounted atop the deaerator vessel.

Also in the traditional design method, the joints of the interconnecting nozzles between the deaerator vessel and the storage vessel cannot be pressure tested. However, the design of the storage vessel (as per the method discussed in "Design Case 3") may help engineering consultants and deaerator manufacturers mitigate the challenges discussed in this article. In this design method, the deaeration and storage vessels can be hydrotested together as an assembly, without increasing the shell thickness of the storage vessel. The joints of the interconnecting nozzles between the deaeration vessel and the storage vessel also can be pressure tested with this design strategy.

The design method in Design Case 3 results in significant material savings and a weight reduction of the storage vessel while meeting the requirement for hydrotesting the design of the complete deaerator assembly. As a result, the entire project is able to achieve cost savings. HP

LITERATURE CITED

1 ASME, "Boiler and pressure vessel code: Rules for construction of pressure vessels," Section VIII, Division 1, American Society of Mechanical Engineers, 2017.

2 Wichman, K. R., A. G. Hopper and J. L. Mershon, "Precision equations and enhanced diagrams for local stresses in spherical and cylindrical shells due to external loadings for implementation of WRC Bulletin 107," Welding Research Council, 2010.

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